

13. *On the ORIGIN of the RIVER-SYSTEM of SOUTH WALES, and its CONNECTION with that of the SEVERN and the THAMES.* By AUBREY STRAHAN, Esq., M.A., F.G.S.¹ (Read February 26th, 1902.)

[PLATE V—Map.]

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I. INTRODUCTION.

THE Welsh rivers, of which I shall endeavour to trace the history in the following pages, flow through a hilly region composed almost wholly of Palæozoic rocks. The greatest height is attained in the Old Red Sandstone of the Brecknock Beacons, which fall but little short of 3000 feet; but the Coal-Measures also rise into escarpments exceeding 2000 feet, and form large areas of mountain-land with an elevation of 1000 feet or more. This high ground is trenched by a series of valleys, of no great length, but important from their depth and from the fact that they penetrate a busy region otherwise difficult of access.

A watershed map of Wales presents at first sight the appearance of a meaningless mosaic, and it will be convenient to commence by disentangling its leading features. A main water-parting, separating the westward- from the eastward-flowing rivers, runs from the northern coast of Pembrokeshire near Fishguard, through the counties of Cardigan and Montgomery. It will be noticed that it commences with an east-and-west trend, but curves gradually northward in Central Wales, keeping near and almost parallel to the west coast. Westward from this water-parting there runs a series of short streams into the Irish Sea; eastward from it flow the Severn and the Wye, both of which traverse Wales in a south-easterly direction, but then turn south-westward to the Bristol Channel. South of the Wye we come to a group of rivers rising on subsidiary water-partings in the counties of Brecknock, Monmouth, and Glamorgan, and three which traverse the counties of Carmarthen and Pembroke from the Central Wales water-parting southward. It is these South Welsh rivers which I propose to discuss in detail. Taken in order from east to west, they include the Usk, with its

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tributary the Afon Lwyd, the Ebbw Fawr and Ebbw Fach, the Sirhowy, the Rhymney, the Taff, the Nêdd or Neath, the Tawe, the Loughor, the Towy, the Tâf, and the Cleddau.

II. RELATIONS OF THE VALLEYS TO THE GEOLOGICAL STRUCTURES.

The Usk takes its rise in the Old Red Sandstone and Silurian rocks near Brecon, and flows eastward at the foot of the great Carboniferous escarpment of the north side of the Coalfield. At Abergavenny it turns southward, and, meandering across the Usk inlier of Silurian rocks, enters the Bristol Channel near Newport. It is to be noticed that it does not make for the synclinal region of Carboniferous rocks, but, on the contrary, cuts right across the area of great upheaval which has brought the Silurian rocks to the surface.

The Afon Lwyd rises on the southern slopes of the northern escarpment of the Coalfield. It then maintains a south-easterly and southerly course, crossing the Blaenavon Fault without being deflected along it, and skirting the margin of the Coalfield in preference to following the dip-slopes towards the central syncline. Finally it escapes from the Carboniferous area by a gorge at Pontypool, and passes close by a Silurian inlier on its way to join the Usk at Caerleon.

The Ebbw Fawr rises in the northern margin of the Carboniferous area, and traverses the Coalfield in a direction slightly east of south. The Ebbw Fach originally followed a similar course, but having suffered the loss of its head-waters by the cutting back of the gorge of the Clydach, as described by Mr. Walcott Gibson,¹ it now commences existence some 3 miles farther south. The two rivers unite at Aberbyg, traverse the central syncline, and, escaping through the Carboniferous escarpment by a gorge at Risca, join the Usk near Newport.

The Sirhowy follows a parallel and similar course. It joins the Ebbw a mile above Risca, and to effect the junction makes a sharp turn eastward, instead of continuing a course which would have led it into the deep Caerphilly syncline.

The Rhymney in its upper part resembles the Sirhowy and Ebbw, but it enters the Caerphilly basin, a deep trough both structurally and physically, and, turning eastward along it, traverses the Carboniferous escarpment at Machen. At first sight the turn might be attributed to the syncline, but it corresponds to the turn made by the Sirhowy, which was away from the syncline, neither to it nor along it. The Rhymney then makes direct for a Silurian inlier near Cardiff, despite the fact that the strata have there been raised 7000 or 8000 feet higher than in the Caerphilly syncline.

The Taff Fawr and Taff Fach differ only from the rivers already described, in the fact that they rise on the dip-slopes of Old Red Sandstone to the north of the Coalfield. Flowing slightly east of south, they cross the Vale-of-Neath disturbance, which here takes

¹ Mem. Geol. Surv. 1900 'Geology of Abergavenny' p. 93.

the form of a wedge faulted down to a depth estimated by Mr. Gibson at about 900 feet, and unite to form the Taff near Merthyr Tydfil. The Taff passes without deflection both the steep central anticline of the Coalfield at Pontypridd, and the Caerphilly syncline to the south of it, escaping from the Coalfield by a narrow gorge at Walnut Tree. Thence its course lies on Keuper Marl.

Some tributaries of the Taff, known as the Cynon and the Rhondda Fawr and Rhondda Fach, rise within the northern margin of the Carboniferous area, and join the main stream at Abereynon and Pontypridd respectively. While flowing almost in the direction of some north-north-westerly faults, they do not actually follow any one of them.

Some small streams west of the Taff deserve a brief mention. The Ely rises on the north side of the central anticline¹ of the Coalfield, and crosses it, steep though it is. It leaves the Coalfield by a break in the escarpment at Llantrissant, which is probably of pre-Triassic age, and then flows eastward to Cardiff over the Secondary rocks which occupy the hollow of the deeply-denuded Cardiff anticline. The Ogwr, Garw, and Llynfi rise in the Coalfield north of the central anticline, the southern limb of which is here replaced by a great east-and-west fracture known as the Moel Gilau Fault. They unite to form the Ogmore, and pass the Carboniferous escarpment by a broad gap, probably of pre-Triassic age. Other smaller streams follow a similar course, the high Pennant land to the south of the fractured anticline offering no obstacle to their assumption of a southerly direction.

It may be remarked of the rivers described in the foregoing paragraphs, that they show parallelism in a south-south-easterly direction, and that their courses are maintained regardless of the structure of the rocks over which they flow. That they are not diverted by the great east-and-west flexures, such as the anticlines and synclines of the Coalfield, is too obvious to need further proof, but their independence of the north-north-westerly system of faulting is not immediately apparent.

The faults of the north-north-westerly system form a conspicuous feature in the structure of the district, and recur at frequent and fairly regular intervals throughout the Coalfield, where their courses and effects are known with considerable certainty. Out of so many faults and valleys, agreeing approximately in direction, it might have been expected that several would coincide. Examination of the maps¹ will show, on the contrary, that coincidence of valley with fault is rare. Of the nine or more long ridges of Pennant which divide the valleys enumerated above, more than half are cut longitudinally by north-north-westerly faults; but not one of the valleys follows a fault, though they sometimes cross the faults at an oblique angle. The want of coincidence is equally marked in the Lower Carboniferous escarpments: neither of the Taff rivers has utilized a fault in passing the northern

¹ The area under consideration is included in the Ordnance Survey (New Series) 1-inch Maps 230, 231, 232, 247, 248, 249, 262, & 263.

escarpment of the limestone, nor is there any fracture along the gorges at Pontypool, Machen, or Risca. At Walnut Tree alone is there a displacement, the coincidence of gorge and fault here presumably being accidental. The parallelism of the valleys with the faults, moreover, is more apparent than real: the faults run a few degrees more east of south than the valleys, and the difference is maintained. Consequently the valleys cross the faults, but at so oblique an angle as to make it the more remarkable that they do not follow them. Lastly, we shall find that, although in the region about to be described the north-north-westerly system of faults is fully developed, the valleys take a different direction. I infer, therefore, that the north-north-westerly system of faulting had no more share in determining the river-system than the east-and-west folds.

We come now to a series of valleys of a different character—they run about west 30° to 40° south, that is, almost at right-angles to those already described. The change of direction takes place in the region in which a set of powerful disturbances first manifests itself (A, B, C, D, & E, on the map, Pl. V); and the direction assumed so closely coincides with that of the disturbances as to prove that it was determined by them.

The Vale of Neath, or Nêdd, forms one of the best examples. The sources of the river lie on the southern slopes of the Old Red Sandstone of Fforest Fawr; and from this upland region the Hepste, Mellte, and (upper) Neath make their way southward, crossing the Lower Carboniferous rocks, and a number of north-north-westerly faults, in narrow and precipitous gorges with numerous waterfalls. The Hepste and Mellte unite, and reach the belt of plicated and overthrust strata which we have called the Vale-of-Neath disturbance (E on the map, Pl. V), at the Glyn Neath Powder-Mills; the Upper Neath reaches the same disturbance a mile farther west, at Pont Nedd Fychau. Once in the disturbed belt the water never leaves it, but follows it in a straight trench-like valley for 12 miles to Neath. There the disturbance dies away, the trench comes to an end, and the river turns southward to the sea at Briton Ferry. The valley is about 1000 feet deep in the Pennant region, and contains a strip of alluvium from a third to half a mile in breadth. The margin of the alluvium, which marks the limits of the lateral swinging of the river, coincides with the margin of the disturbed strata, and the walls of the valley are formed by the unbroken strata of the north and south sides of the disturbance. The alluvial flat, however, ceases at the Powder-Mills, where limestone and Millstone Grit are thrown up along the axis of the disturbance. From that point eastward a ridge marks the axis of the disturbance, except at the spots where it is crossed by the Taff Fawr, Taff Fach, and a gap at Penderyn.

Travelling 7 miles to the north-west over undisturbed strata, we reach a second belt of plication and fracture, which we have called the Cribarth disturbance (D on the map, Pl. V), after a hill in which its

effects are well exhibited. Here again is a no less intimate connection between disturbance and river. The Tawe is fed by streams from the Old Red Sandstone. These unite before reaching the Carboniferous Limestone escarpment, and pass that great feature in a winding gorge, near, but not along, the line of the Cribarth disturbance. In the Coal-Measures, however, a little to the south, the river falls into the line and follows it thence to Swansea, a distance of about 12 miles. The disturbed belt is less closely defined than that of the Vale of Neath; but evidence of its existence recurs at frequent intervals. The Red Vein of coal, for example, is thrown down to the north-west at Ystalyfera, and the Hughes Vein is similarly shifted near Pontardawe. Some great north-and-south faults are deflected by it in a manner described later on; while, lastly, in following the line of disturbance to Morriston near Swansea, we are led to an extremely deep faulted syncline, known as the Tir Canol Fault, which has been thoroughly explored in working the coals under the alluvial flat. There is no known fault, however, in the gorge by which the Tawe traverses the southern escarpment of the Pennant Grit at Swansea.

The Loughor River rises in the northern margin of the Carboniferous area, and runs in a direction slightly west of south. It follows no great line of disturbance, but meanders across the Coalfield, passing several considerable north-north-westerly faults and east-and-west folds without deflection.

The Towy flows wholly on the north side of the Carboniferous area. It is fed by a number of streams from the main water-parting which runs through the counties of Pembroke, Cardigan, and Montgomery; but these tributaries are all gathered into a main stream, the course of which from Llandovery by Llandilo to Carmarthen is obviously connected with the strike of the Silurian and Ordovician rocks. Recent work by my colleagues Messrs. Cantrill and Thomas¹ has shown that that strike is due to movements of great energy, which have not only rendered the strata vertical, or nearly so, along a belt of country some 2 miles in width, but have caused much overthrusting. The disturbance (A on the map, Pl. V), which may be conveniently named after Llandilo, is allied in direction and character with those of Cribarth and Neath, as will be shown in discussing the age of the various movements evidenced in South Wales. Near Carmarthen, where it loses energy, it releases the river, which then takes a southward direction into Carmarthen Bay. Before quitting the Towy, however, brief allusion may be made to a small tributary known as the Cennen, which rises in a strike-valley at the foot of the Carboniferous-Limestone escarpment. The valley follows a subsidiary disturbance (B on the map, Pl. V) parallel to the Llandilo movement, the effect of which has been to form a faulted syncline, and to introduce a conspicuous little crag of limestone, known as Cerig Cennen, into the middle of the outcrop of the Old Red Sandstone. The drainage

¹ Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

of the strike-valley is carried partly westward by the Cennen, and partly eastward by a stream flowing eastward along the same line of strike, the parting between the two streams being ill-defined. Both streams leave the line of strike as soon as the disturbance loses intensity, and turn northward into the Towy.

The remaining rivers to be mentioned are the Tâf and the Cleddau. Rising west of the region affected by the Llandilo disturbance, they pursue an uninterrupted course from their sources in the main watershed to the southern coast of Pembrokeshire. In so doing they ignore great east-and-west folds, which are in a direct line with the pre-Triassic folds of South Glamorgan; the Western Cleddau, for example, crosses in succession an area of Archæan rocks and the synclinal region of the Coalfield. In Milford Haven the valley pursues a westerly course along the strike of the beds, and thus gives, what is rare in South Wales, an example of a valley coinciding with the pre-Triassic strike.

The influence of the group of south-westerly disturbances may be inferred also from a consideration of the catchment-basins of the rivers. The Vale-of-Neath disturbance dies away a short distance east of the Taff Valley; the Usk consequently escapes its influence, and rises in the next belt of disturbance, namely, that which I have named after Llandilo. The Llandilo disturbance broadens out in the neighbourhood of Builth; the Wye consequently, and the Upper Severn, go beyond it to the main water-parting of Wales for their sources. Similarly the Pembrokeshire Tâf and the Cleddau rise in the main water-parting, and flow directly from it, both the Llandilo and the Cribarth disturbances having died out before entering their catchment-basins. All the rivers, in fact, have assumed a course at right-angles to the main water-parting, except those which have been deflected along local subsidiary disturbances. This prevalent, or normal, direction of flow locates the axis of the elevatory movement by which the drainage was initiated, and it is of the greatest interest to note that that axis is parallel to those subsidiary disturbances which have controlled the river-courses wherever they are developed.

III. THE AGE AND CHARACTER OF THE STRUCTURES.

That the movements which have affected this region are characterized by their direction is apparent at once, and this fact alone suffices to distinguish them into the three systems, the directions of which are expressed by Prof. Lapworth under the names of Armorican, Charnian (or Hercynian of Suess), and Caledonian. These three systems, moreover, differ no less in character than in direction.

(1) The east-and-west, or Armorican, movement, was one of compression from south to north. It reached its greatest intensity in Somerset and Devon, but extended so far north as to fold sharply the Lower Carboniferous rocks south of the Coalfield, and to throw the Coal-Measures themselves into great synclinal and anticlinal

felds. The existence of the Coalfield is, in fact, due to a broad synclinal structure produced by that movement. The period during which the Armorican movement was active in this district is well defined. It affected equally all rocks from the Silurian to the youngest Coal-Measures, and was therefore post-Carboniferous. On the other hand, it affected neither the Keuper in South Wales nor the New Red rocks (including the so-called Permian) in Devon, and was therefore pre-Triassic.

The movement is characterized by folding and overthrusting, and was essentially of an elevatory type. It marked the commencement of a prolonged continental epoch, and was the direct cause of the enormous denudation which took place between Carboniferous and Triassic times. A river-system must have existed; and Sir Andrew Ramsay even attributed the Welsh valleys to erosion continuously proceeding 'ever since the close of that great continental epoch that ended with the influx of the Rhætic and Liassic sea.'¹ I should suggest that the erosion more probably took place during the continental epoch than after its close; but, so far as I am aware, no part of the valley-system now in use can be proved to be of this early age, except some breaks in the escarpment already mentioned, and certain broad low-lying tracts, such as the Vale of Glamorgan and the Bristol Channel, which are, or have recently been, deeply over-spread by Keuper Marl. That the existing rivers make for these tracts is true; but it is to be remembered that in so doing they ignore the Armorican folding which determined the positions of those tracts, and were therefore themselves determined by another cause.

(2) The north-north-westerly, or Charnian, faults show a remarkable persistence through England, Wales, and probably Scotland.² So far as South Wales is concerned, it can be proved that the movement was in progress after the deposition of the Lower Lias, but that it had commenced at an earlier date; for the faults, though they affect strata of all ages, are more considerable on the average in the Carboniferous than in the Secondary rocks. In other parts of the kingdom it can be shown that the movement was in full activity in post-Cretaceous times, for its effects are shown in the Chaik both of Devon and Yorkshire. If the injection of the innumerable dykes of the North-west of the British Isles, which have this direction, was due to the same movement, the period of activity is extended into Eocene times, and, as a fact, one of the north-north-westerly fractures in Staffordshire has been injected with basalt of a Tertiary type.³ Whatever their age may be, however, the north-north-westerly faults had no share in determining the courses taken by the rivers; and this I believe to be true not only of South Wales, but of other districts. The Vale of Clwyd would seem to be an exception: the existence of the Vale,

¹ 'Physical Geology & Geography of Great Britain' 6th ed. (1894) p. 363.

² Geol. Mag. 1890, p. 111.

³ W. W. Watts, Proc. Geol. Assoc. vol. xv (1898) p. 397.

however, is due, not directly to the fault, but to the introduction by the fault of a strip of soft strata among the Silurian slates and grits.

The Charnian movement, as manifested in the north-north-westerly faults, was essentially one of subsidence. It is characterized by faults which hade normally to the downthrow, and each fault represents a gain in horizontal extent of the rocks that it shifts, proportionate to its throw and the lowness of its hade. In the Coalfield alone, this gain must amount to some hundreds of yards.

(3) The age of the west-south-westerly, or Caledonian, movement in South Wales is more difficult to determine, for it did not extend to the area now occupied by Secondary rocks. The belts of disturbance attributable to this movement in the area under consideration may be enumerated as follows:—

The Vale-of-Neath disturbance, which runs from the Old Red area north of Dowlais to Neath, a distance of 25 miles, in a general direction of west 27° south (E on the map, Pl. V).

The Cribarth disturbance, which follows at a distance of 7 miles, runs from Fan Gihirych to near Swansea, a distance of 20 miles, in a general direction of west 40° to 50° south (D on the map).

The Tair-Carn disturbance is an anticline which arches up the Millstone Grit 8 miles north of the Cribarth disturbance. It runs in about the same direction, but its course through the Coalfield is still under investigation (C on the map).

The Cerig-Cennen disturbance runs about 2 miles north of Tair Carn, in a direction of west 20° south (B on the map).

The Llandilo disturbance runs a mile or two farther north again, in a direction of about west 17° to 20° south, but curves northward to west 45° south (A on the map¹).

Direct evidence proves no more than that these disturbances were of post-Carboniferous age; and from the fact that they resemble the east-and-west folds in being due to a movement of compression, and do not differ widely from them in direction, I was disposed at first to regard them as contemporaneous with that system. That view is untenable, for the following reasons:—The two systems are developed in different regions, and do not amalgamate; the Caledonian movement lost energy in the district in which the Armorican movement was most intense, the one displaying itself in Central Wales, the other in Devon and Somerset. Secondly, the difference in direction, though slight, is maintained. Lastly, the Armorican disturbances were due to a movement or impulse from the south, and die gradually away northward in South Wales, while the Caledonian movement records an impulse from the north, and dies gradually away southward in the same region. The detailed structure of the Caledonian disturbances, enumerated above, indicates this thrust

¹ The re-surveying of the district extends no farther north than Llandilo, and I am, therefore, unable to say what further disturbances occur to the north of that town.

from the north, for at the head of the Vale of Neath the Carboniferous Limestone has been thrust southward over the Millstone Grit¹; while the relations of the Ordovician and Silurian rocks in the Llandilo neighbourhood shew that the fold takes the form of a great sigmoidal curve, supplemented in places by fracture and thrusting from the north.²

It being evident, therefore, that the Caledonian movement was distinct in character, distribution, and, presumably, age from the Armorican, it remained to compare it with the north-north-westerly faults of the Charnian movement. Theoretically the later movement would shift the structures due to the earlier; and this test, when applied to the Charnian and Armorican structures, gave a definite result, for the north-north-westerly faults maintain their direct courses across the east-and-west folds everywhere. As regards the relations of the Charnian with the Caledonian movements the evidence is as follows:—

A considerable number of north-north-westerly faults have been mapped on either side of the Vale-of-Neath disturbance, but a few only could be traced across it. At Penderyn there is a cross-fracture, but the details of the structure are hidden by Drift. Of the many faults visible in the ravines of the Hepste, Melte, and Upper Neath, not one could be recognized in the belt of disturbed ground. The Glyn Corrwg Fault reaches the disturbance on its south side at Blaengwrach. It has there a large westerly downthrow, but no fault of corresponding magnitude was to be found on the north side of the disturbance. The strata, however, are much plicated; and it is possible that the fault continues, though it is certainly smaller. The behaviour of the Pen-y-Castell Fault scarcely admits of this explanation. It runs into the disturbance from the south 3 miles below the Glyn Corrwg Fault, and has been proved at a point about 2 miles south of the intersection to have a westerly downthrow of 118 yards. The bold Pennant features on the north side of this part of the Neath Valley give facilities for a full investigation, but I was unable to find any trace of the Pen-y-Castell Fault. Two explanations are possible: either the fault died away, or it turns abruptly, through more than a right-angle, along the Vale of Neath. The latter involves the supposition that a line of weakness already existed along the Vale, which is tantamount to saying that the Caledonian preceded the Charnian movement. I put forward this explanation in 1900 (while the Survey was in progress), and it seemed to be supported by the fact that a north-and-south fault crossed the Cribarth disturbance near Pen Wyllt³; but since then further evidence has been obtained, leading to an opposite conclusion.

Both the Vale-of-Neath and the Cribarth disturbances are crossed

¹ Mem. Geol. Surv. Summary of Progress for 1898, pl. ii, facing p. 118. The illustration will be reproduced in the Memoir on Sheet 231 (Merthyr Tydfil), in preparation.

² Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

³ *Ibid.* 1898, pp. 118, 119.

by the extremely deep trough-faults known as the Rhydding and the Dyffryn Faults. The Rhydding Fault has a westerly downthrow of 800 yards at its maximum, and of 580 yards at its intersection with the disturbance. The Dyffryn Fault has an easterly downthrow of about 300 yards at the intersection. Both faults had normally to the downthrow, and therefore in opposite directions. If, then, they were crossed by a later fracture, their surface-positions should be shifted in opposite directions; but, so far from this being the case, both are shifted, or rather curved, considerably to the south in crossing to the north side of the Cribarth disturbance. The same effect is produced on other faults, notably the Gardener's Fault at Clydach; and it may be the explanation of a remarkable twist in the Gnoll Fault at Neath, the tracing of which has puzzled successive generations of coal-miners. It would seem that the whole block of country north of the disturbance has moved south-westward relatively to the block south of it—a movement which would account also for the difference in level noticeable in strata on either side of the disturbance. The north-north-westerly faults suffered the shift, and therefore preceded the Vale-of-Neath and Cribarth disturbances. In the case of the Llandilo disturbance, Messrs. Cantrill and Thomas have traced several considerable north-north-westerly faults through the upturned Lower Carboniferous and Silurian rocks which flank the axis, but have found no clear case of one of these faults cutting clean through the axis itself, along which the overthrusting sets in.

IV. DETERMINATION OF THE RIVER-SYSTEM BY A CALEDONIAN MOVEMENT.

The behaviour of the rivers now becomes explicable. They were initiated by the latest of the three systems of movement, and during a period of elevation, which is evidenced by the character of that system. An axis, presumably of maximum elevation, formed the water-parting, and from it the rivers flowed east and west on its two sides respectively, but some subsidiary axes of elevation formed minor water-partings, or locally diverted the rivers in their courses from the major axis. Thus the Severn, Wye, Towy, Tâf, and Cleddau rise in the main water-parting, and take a normal course from it; but the Towy, encountering the Llandilo disturbance, is deflected along it to the south-west, so far as the disturbance runs. The Usk rises in the Llandilo disturbance, assumes the normal direction and keeps to it. The Tawe, rising in the same subsidiary water-parting, encounters the Cribarth disturbance, and is deflected along it to the south-west. The Neath and the Taff rise in an elevated region which is in the line of the Cribarth disturbance, and assume the normal course; but the Neath is caught in the Vale-of-Neath disturbance, and is deflected by it. The Taff encounters the same disturbance, but, for a reason explained subsequently, crosses it. The group of rivers, including the Afon Lwyd on the east and the Ogmore on the west, rise south of the belt affected by the subsidiary disturbances and pursue a normal course.

The fact that the Taff crosses the Vale-of-Neath disturbance needs further explanation. The effect of these subsidiary disturbances upon the drainage is attributable to their having been axes of elevation. The strata are crumpled up and overthrust along them. More than this, the Vale-of-Neath disturbance, where it so effectually traps the head-waters of the Neath, is accompanied by an uplift of the strata on its south side of about 600 feet, and would thus be likely to throw a southward-flowing river out of its course. Where it is crossed by the Taff it assumes a different structure. There Mr. Gibson finds that the disturbance is not accompanied by an uplift of the south side, but that it takes the form of a faulted syncline about a mile broad, along which a wedge of Carboniferous Limestone is dropped into the heart of the Old Red country, to a level of about 900 feet below its normal position. The disturbance dies out about 3 miles to the north-east of the Taff Fach, and the absence of those evidences of compression which abound farther to the south-west, may be regarded as symptoms of diminishing energy. As a result no intercepting feature was formed, and the Taff Fawr and Fach kept their southward courses.

The fact that the rivers ignore the structures produced by the Armorican and Charnian movements proves that the physical features produced by those structures had either been completely levelled by denudation, or, what is more probable, had been buried under later formations, after being partly levelled down. Of the elevation and vast amount of denudation which resulted from the pre-Triassic Armorican folding we have ample proof, as shown by Ramsay more than fifty years ago.¹ To mention one example—the Keuper Marl rests directly upon Silurian strata near Cardiff. At that spot there must have been removed in pre-Triassic times about 3500 feet of Old Red Sandstone, 1400 feet of Carboniferous Limestone and Millstone Grit, and not less than 2800 feet of Coal-Measures, or about 7700 feet of strata in all.² Evidence to this effect is yielded also by many rocky inliers of Carboniferous Limestone in the Keuper Marl, for much of the landscape produced at that early period still survives, though later erosion has only partly freed it from its envelopment of Secondary rocks.

Of these inliers many sank beneath the water in Triassic time, but others survived as islands in the Liassic sea. In such cases the Lias always overlaps the Trias; and it may be inferred that the same overlap took place along the main coast-line of the Liassic sea. Evidence exists (in the shape of veins filled with hæmatite, and even with marl, in the limestone) that the Trias extended farther and to a greater elevation than now, both to the west in Gower and to the north near Cardiff. Presumably the Lias extended still farther; but the fact that it assumes a littoral type in parts of South Wales, proves that its limits were not far distant. In these

¹ Mem. Geol. Surv. vol. i (1846) p. 297.

² I give here measurements recently obtained. Ramsay's estimates were rather greater.

conclusions I agree closely with the views expressed by Sir Andrew Ramsay in 1872.¹

In speaking of the later Secondary rocks, he stated his opinion that it was 'even possible during the Upper Cretaceous period Wales may have sunk almost entirely beneath the sea.' This hypothesis, so guardedly put forward, is likely I think to receive support. The Upper Cretaceous rocks, though they thin westward, are well developed at Haldon in Devon. They have there overlapped all the older Secondary formations, except a small part of the Red Rocks, and must obviously have overspread much of the Palæozoic area. In the Midlands also, as well as in the North-eastern Counties referred to by Ramsay, they overlap the Upper Jurassic strata with a marked unconformity, while finally they re-appear in Scotland and the North of Ireland. This overlap by, and wide extension of, a purely marine formation, proves a period of general subsidence, which possibly was connected with the equally wide development of the subsiding movement indicated by the north-north-westerly, or Charnian, faults—these, as we have seen, having been in part only of post-Cretaceous age. If we can add to these arguments that the great uplift was due to activity of the Caledonian movement in post-Cretaceous times, the possibility suggested by Ramsay becomes a probability, for it would imply that the uplands of South Wales had not come into existence, and that there was therefore no obstacle to the advance of the Upper Cretaceous sea. I may add that Mr. Jukes-Browne, on a totally different line of argument, has concluded that the Upper Chalk covered all Wales, except a small area overlying the present Snowdon range.² A statement, by which Ramsay was influenced, that no trace of Upper Cretaceous rocks exists in South Wales, except for some flints in a gravel on the Wye, is not wholly correct, for small fragments of flint occur sparingly in the Glacial Drift of South Glamorgan. I attach no importance to the fact, however, for they may have travelled far. Their great abundance in the 'raised beach' of parts of Cornwall is more significant.

Eocene gravels in their turn overlapped the Chalk. Evidence of this has been obtained by Mr. Clement Reid in the composition of the Bagshot gravels of Dorset,³ and recently by Mr. H. B. Woodward at Lyme Regis.⁴ Part of the evidence, however, consists in the occurrence of pebbles of Oolitic rocks in the gravels; a fact which proves that the Chalk had already been denuded, and that the uplift in the west had therefore commenced. The inference that the limit of the Eocene basin was not far distant receives support from the character of the Eocene strata, and the rapidity of the change undergone by them in a westerly direction. That they extended over South Wales seems scarcely probable.

¹ Quart. Journ. Geol. Soc. vol. xxviii (1872) p. 148. The substance of that paper is reproduced in his 'Physical Geology & Geography of Great Britain' 6th ed. (edited by H. B. Woodward) 1894, ch. xxxi, pp. 346-66.

² 'Building of the British Isles' 1888, p. 194.

³ Quart. Journ. Geol. Soc. vol. lii (1896) pp. 490-95, & vol. liv (1898) pp. 234-38.

⁴ Mem. Geol. Surv. Summary of Progress for 1901. (In the press.)

It is a reasonable assumption, therefore, that the river-system of South Wales was initiated upon a slope of Upper Cretaceous rocks, by which all features in the Palæozoic strata were blanketed over, and that in this may be sought the explanation of the complete disregard by the rivers of structures due to the Armorican and Charnian movements. The case is comparable to that of a part of Dorset, where folded Jurassic rocks form the substratum to the Upper Cretaceous. There also the rivers, initiated upon a Chalk-plain by post-Cretaceous movements, have maintained their courses after the removal of the Cretaceous rocks, and occupy valleys which have no connection with the structures in the Jurassic strata.¹

V. CONNECTION WITH THE COURSE OF THE SEVERN, AND OF THE THAMES AND FROME.

The courses taken by the Severn and the eastward-flowing rivers of the South of England were discussed by Sir Andrew Ramsay in the paper already quoted. The southward direction assumed by the Lower Severn was accounted for, on the supposition that the country received a tilt after Miocene times, by which a slope to the north-west was produced. The Chalk having been denuded along the route which the Severn was thus induced to follow, the Chalk-escarpment came into existence. In order to account for the easterly direction taken by the Thames and Frome, he found it necessary to suppose a later tilt of the country by which a slope to the east was produced. The argument, however, in favour of the tilt to the north-west was not regarded as convincing, and the course taken by the Severn remained unexplained.²

The evidence on which the history of the eastward-flowing rivers of the South of England may be reconstructed is fairly complete. The initiation of the two main lines of drainage, the Kennet-Thames and the Frome-Solent, has been discussed elsewhere,³ and it will suffice now to recall the fact that they follow the London and Hampshire synclines respectively, and collect their tributaries from the intervening anticlines. Further, it was shown that these synclines and anticlines, while running east and west, are arranged in échelon along a line which is parallel to the Chalk-escarpment.

The Chalk-escarpment now forms the main water-parting through much of its range across England, as shown on the map (Pl. V). There is reason to think that originally the coincidence between escarpment and water-parting was closer even than it is now. The escarpment, in that part of it which extends from Dorset to the borders of Hertfordshire, diverges from the water-parting three times, namely, in the Vales of Wardour and Pewsey, and in the valley of the Upper Thames. In all these cases, rivers rising in

¹ Mem. Geol. Surv. 'Geology of the Isle of Purbeck' 1898, p. 233.

² The theories put forward by Mr. S. S. Buckman in Proc. Cotteswold Nat. Field Club, vol. xiii (1900) p. 175, following the lead of Prof. W. M. Davis, appear to me to transgress the limits of legitimate speculation.

³ Mem. Geol. Surv. 'Geology of the Isle of Wight' 2nd ed. (1889) p. 248, & Proc. Geol. Assoc. vol. xiv (1896) p. 406.

the low-lying Oolitic region flow eastward against the general run of the country, and make their way through the Chalk-escarpment to the Thames or Frome. The explanation did not escape Ramsay. Their courses were initiated upon an eastward slope of Chalk, and the distance from their sources to the existing escarpment is a measure of the recession of the escarpment since the initiation.¹ The amount of denudation accomplished in this main escarpment is not out of proportion to that which has cut back the North and South Downs of the Wealden area to their present position in the same period of time. The original position of the escarpment, therefore, coincided closely with the water-parting of the eastward-flowing rivers. But the general dip of the Chalk is sufficient to carry it high into the air over the line of the water-parting, and it is evident that it cannot have continued westward. In other words, there must have been an anticline along the line of the water-parting. Traces of such an anticline have been detected by Mr. Buckman in the Vale of Moreton.²

We may now compare this main water-parting of the South of England with that of South Wales. From both, the rivers take a normal eastward course. On the west side of the one the rivers are deflected to a south-westerly course, as in the case of the Avon and Severn, or to a north-easterly course, as in the case of the Ouse and Nen. Along the other a similar deflection takes place, as in the case of the Teifi, or of the various streams previously described. The Chalk-escarpment again, in Suffolk and Norfolk, where the tilt is less pronounced, ceases to form a water-parting, as was the case with the Llandilo, Cribarth, and Neath axes in Wales. Lastly, the axis of upheaval in the Chalk is parallel to the Caledonian disturbances which initiated the Welsh rivers, and took place in that area in which the geographical arrangement of those lines of disturbance would have led us to look for it. I infer, therefore, that the initiation of the South-Wales and South-of-England river-systems, and the southward deflection of the Severn were due to one and the same movement, and that in that movement, though accompanied by east-and-west folding in the London and Hampshire Basins, the Caledonian direction was paramount.

VI. DATE OF THE INITIATION OF THE RIVER-SYSTEMS.

Evidence for the age of the Caledonian movement, though deficient in South Wales, is fairly definite in England. The movement took an equal share with the Armorican folds of the London and Hampshire Basins in determining the Thames and Frome systems, and was presumably contemporaneous with them. But the age of those Armorican folds is definitely fixed by two facts. They were post-

¹ The existence of certain valleys breaching the escarpment, but not now occupied by streams, is explained by Prof. Gregory, 'Natural Science' vol. v (1894) p. 97, on the supposition that they carried the drainage from that part of the Chalk-plain which has perished.

² Quart. Journ. Geol. Soc. vol. lvii (1901) p. 146.

Oligocene, inasmuch as Oligocene strata have been uplifted by them in the Isle of Wight; they were pre-Pliocene, inasmuch as no Pliocene strata have been folded into either syncline.¹ The uplift of the Chalk, therefore, along the Caledonian axis, the position of which has been inferred by reference to the Chalk-escarpment, took place between the deposition of those formations.

But in view of the close analogy which holds between the Caledonian disturbances in South Wales and this Caledonian uplift of the Chalk, not only in direction, but in their effect upon the river-drainage, these also may be inferred to have been contemporaneous, and the initiation of the whole of the river-systems referred to in this paper would have taken place between the Oligocene and Pliocene Periods.

Passing in review the principal movements which have affected the regions referred to in this paper since the Carboniferous Period, we may construct a chronological table as follows:—

<i>Date.</i>	<i>Character.</i>	<i>Direction.</i>
Post-Carboniferous } Pre-Triassic	Elevatory movement. Impulse from the south.	Armorican.
Do. do.	Subsiding.	Charnian.
Intra-Cretaceous ... {	Elevatory. Impulse from the south.	Armorican.
Post-Cretaceous and perhaps Eocene... }	Subsiding.	Charnian.
Post-Oligocene } Pre-Pliocene..... }	Elevatory. Impulse from the north.	Caledonian.
Do. do.	Elevatory. Impulse from the south.	Armorican.

Of all these, the post-Oligocene movements alone have had any direct influence in determining the existing river-systems. There may be reluctance in accepting this conclusion, on the ground that it assigns a late date to great movements and to denudation on a sweeping scale. Not only, however, have movements as great or greater taken place at a still later date in other parts of the world, but we have in the Isles of Wight and Purbeck direct evidence of the date of the disturbances and of the great erosion consequent upon them. It should be remembered also that, of the vast mass of Palæozoic strata which has been removed from South Wales, by far the greater part was denuded in pre-Triassic times. Post-Oligocene denudation need be called upon to account for little more in that region than the removal of the Upper Cretaceous rocks, and the excavation of the valleys occupied by the existing rivers.

¹ C. Reid, Mem. Geol. Surv. 'Pliocene Deposits of Britain' 1890, p. 69. Prestwich's view, that the Chalk- and Oolite-escarpments were of Pleistocene age, has not met with acceptance. It was ably combated by Prof. Gregory in his paper on the Evolution of the Thames, 'Natural Science' vol. v (1894) p. 97.

EXPLANATION OF PLATE V.

Map of South Wales and of a portion of South-Western England, on the scale of 30 miles to the inch, illustrating the relation of the water-partings to the geological structure.

The main water-parting of South Wales, and the limits of the basins of the Thames and Frome, are shown by thick broken lines; other water-partings being indicated by heavy dotted lines.

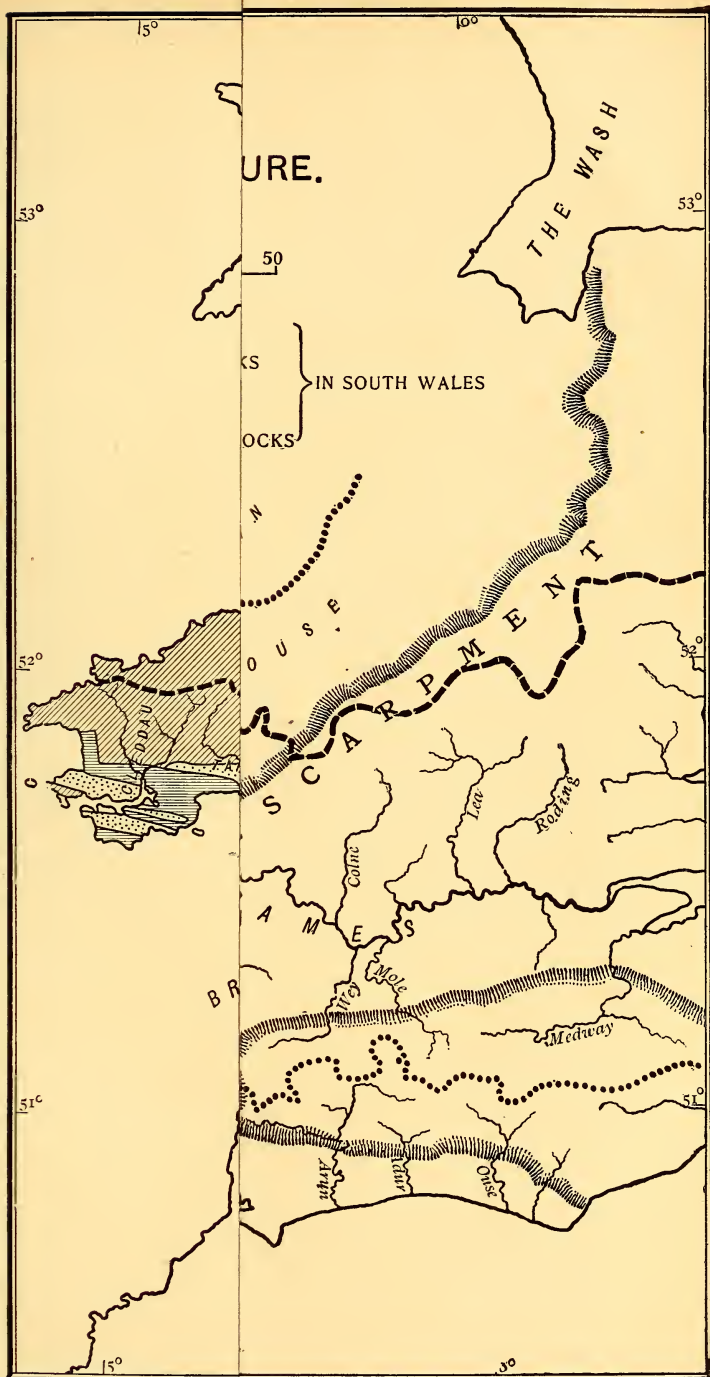
Strong black lines indicate the Caledonian disturbances of South Wales referred to in the text:—

A = The Llandilo disturbance.	D = The Cribarth disturbance.
B = The Cennen do.	E = The Vale-of-Neath do.
C = The Tair-Carn do.	

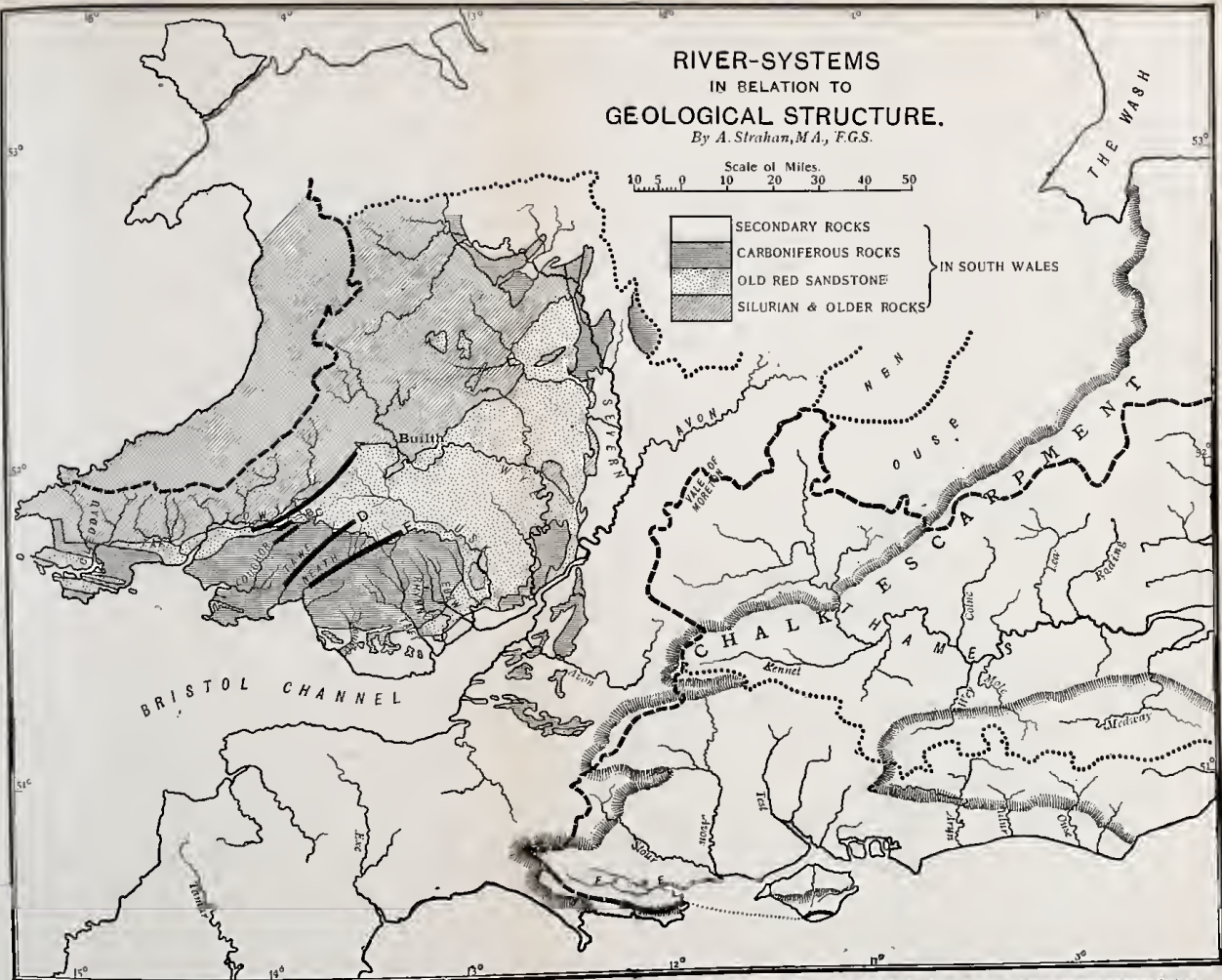
DISCUSSION.

Prof. GROOM said that he had listened with great interest to the paper, since it dealt with an area with part of which he was familiar. He regretted, however, that the term 'Caledonian' had not been used in conformity with its original application, and had been employed to designate movements which had taken place in a different district and at a different time from those which gave rise to the 'Caledonian Range' of Suess. This, he was afraid, might lead to confusion.

As to the substance of the paper, while there was much in it with which he could agree, he felt great hesitation in accepting the Author's conclusions on one important point. According to the Author, the movements that gave rise to the south-westerly trend of the rocks in Central Wales were of later date than those that produced the Armorican branch of the Hercynian system. The speaker thought, however, that the evidence available tended the other way. The general progress of folding in Britain, as on the Continent, appeared to have been from the north-west; and the disappearance of the north-easterly and south-westerly folds in the southern parts of Wales and Ireland along the line of the Armorican folds, seemed to be best explained by supposing the latter to have been superimposed on the former. Moreover, there was direct evidence that the folding termed Caledonian by the Author had made very considerable progress in pre-Carboniferous times. Thus in Radnorshire, and farther north-east in Shropshire, important movements, during the Llandovery Period, appeared to have already impressed on the beds a south-westerly trend. Further movements had probably taken place in later Silurian times, and again before the deposition of the so-called Upper Old Red Sandstone and Carboniferous Limestone. In the Berwyn Hills, indeed, according to recent investigations by Mr. Philip Lake and the speaker, the folding in pre-Carboniferous times had been so great that, at a time when the Carboniferous Limestone was horizontal, the underlying beds already dipped at 70° or more. Here, as also in the neighbourhood of Llandilo, the creep had been from the north-west, as the Author had maintained for the latter area; and in both cases inversion of the beds occurred on the south-east. Doubtless later movements in the same



[The main water-part broken lines; other water-partings being indicated by h the Llandilo disturbance, B=the Cennen, C=the Tair C



[The main water-parting of South Wales, and the limits of the basins of the Thames and Frome, are shewn by thick broken lines; other water-partings being indicated by heavy dotted lines. Strong black lines indicate the Caledonian disturbances of South Wales:—A=the Llandilo disturbance, B=the Cennen, C=the Tair Carn, D=the Cribarth, and E=the Vale-of-Neath disturbance.]

direction had occurred along the Welsh Border, as observations in Shropshire seemed to indicate; but it was probable that much of the folding along this tract took place in Old-Red-Sandstone times, and therefore at an earlier date than that of the Hercynian folding.

As to the faults showing a 'Charnian' direction, the speaker would like to ask whether, like the different systems of parallel folds, they might not be of various ages.

Mr. A. E. SALTER thought that this interesting paper had brought out two most important points to students of post-Pliocene geology: firstly, the action of long-continued earth-movements which have affected the drainage-systems of Southern and Central England; and, secondly, that subaërial denudation has taken place on a large scale. The presence at high elevations north of the present Thames Valley, of *débris* from the Lower Greensand of the Wealden anticlinal which can be traced from Hampstead, Barnet, etc., right across Southern and Eastern Essex to Walton-on-the-Naze, pointed to an accentuation of the east-and-west (Armorican) folding in comparatively recent times.

The Author did not seem to have taken the Oolitic escarpment into serious account. As this was on a grander scale than that of the Chalk, it appeared to deserve more consideration, especially as it could be shown by its outliers to have had much influence on the formation of the Severn-Avon Valley. He noted that the syncline of the Thames Valley was stated to have been initiated in post-Oligocene and pre-Pliocene times; and wished to enquire whether the presence of Lower Pliocene fossils at Lenham (600 feet above Ordnance datum) did not require a later age to be assigned to them.

Mr. GREENLY observed that evidence as to the relative ages of movements along Caledonian and Charnian lines was obtainable in the Anglesey region within an area of quite moderate size. The dominant strike of the Carboniferous and various older rocks was here north-east to south-west, or Caledonian; but the lines belonging to this series were cut and shifted by a considerable number of fractures having a north-westerly to south-easterly, or Charnian trend. The dykes also of the series, regarded by the speaker as probably of Tertiary age, ran in the same north-westerly to south-easterly direction; and, moreover, often coincided with lines of displacement. Finally, in the Central area, dykes with this trend were broken and shifted by still later north-easterly to south-westerly, or Caledonian, fractures. It was thus clear that Caledonian and Charnian movements had occurred alternately one with the other, within the limits of what is now the island of Anglesey.

Mr. P. LAKE said that he was somewhat surprised to find that the views of the Author were so similar in many respects to those which he had himself advanced two years ago concerning the development of the rivers of North Wales; views which were at the time adversely criticized by the Author. He was completely in agreement with the Author in believing that the north-east to south-west valleys were directly determined by earth-movements, and that the other river-valleys were not so determined; and he looked upon the valley of the

Bala Fault and the other parallel valleys in North Wales as belonging to the same system as the valleys of the Neath, etc., described by the Author. He did not infer that the Bala Fault, as a whole, was of modern origin, but he believed that a certain amount of displacement had taken place along the line of this fault in comparatively recent times; and he could see no reason why the Author (who attributed the north-east to south-west valleys of South Wales to a modern system of earth-movements) should have denied the possibility of displacement along the Bala Fault during the same period. In support of the view that such movements actually had taken place in a comparatively recent geological period, he pointed to the fact that, whatever might be the nature of the rock on the two sides of this fault, the whole country on the south side stood at a much higher level than it did on the north. He also observed that at least one recent earthquake had taken place along the line of the Bala Fault, and that earth-rumblings were commonly heard at several farms which stand upon the fault. All this was equally evidence in favour of the Author's views.

In conclusion, he remarked that the only essential difference between his own views and those of the Author, was that the latter seemed to think that the north-easterly to south-westerly folds were initiated at the same time as the rivers; whereas he (the speaker) believed that a general drainage-system was first established, and that these folds were subsequently formed across the direction of the main drainage-lines, and produced very extensive changes in the original courses of the rivers.

Dr. H. R. MILL said that the watershed which coincided with, or ran parallel to, the Oolite-escarpment, breached only by the Humber, struck him as the most remarkable feature in the hydrography of England. There was nothing in the existing configuration to account for the position of this watershed; and he asked whether the series of events so interestingly outlined by the Author might possibly afford an explanation.

Prof. WATTS thought that the anticline mentioned by the Author supplied a necessary modification of Ramsay's views with regard to the origin of the Severn and Thames. The recent age of the movements postulated by the Author presented little difficulty to those who had seen the great effects of recent movements and denudation in the North of Ireland and the Inner Hebrides.

The PRESIDENT said that the meeting had had the advantage of listening to the inferences respecting the river-drainage of South Wales, drawn by a man whose actual work in the field for several years past had made him thoroughly familiar with the detailed geology of the district in question. It appeared to him that the Author's conclusion, that the apparently complicated drainage-system could be simply explained by the theory that it was initiated upon a gently sloping Cretaceous rock-mantle which overspread and masked the folded and faulted rock-formations of earlier date, and was itself locally deformed by later crust-movements having a Caledonian trend, was not only new, but most significant. In lecturing upon the

various directions of crust-creep in the British Islands, as shown by the long axes of the folds and the run of the faults, he had himself taught for many years that they were four in number—namely, (1) a northerly-and-southerly, longitudinal or Malvernian; (2) an easterly-and-westerly, latitudinal or Armorican; (3) a north-easterly and south-westerly, diagonal or Caledonian; and (4) a north-westerly and south-easterly, diagonal or Charnian. These names were especially useful when employed as indices of direction, without regard to geological time. Thus the Caledonian deformation is distinguished by a north-westerly to south-easterly creep and a north-easterly to south-westerly trend; the terms ‘creep’ and ‘trend’ being related one to the other much as are dip and strike. Folds with a Caledonian trend were as old as the Torridonian and as new as the Tertiary. He saw no objection, therefore, to the employment of the term ‘Caledonian’ for the post-Cretaceous system of north-easterly to south-westerly folds of the Towy and the Tawe.

With regard to the Upper Severn, he had himself advocated the opinion that it originally formed a part of the system of the Dee, the gorge through the Wenlock Edge at Ironbridge having probably been cut in earlier Glacial times.

It appeared to him that the Author’s suggestion that the basins of the Thames-Kennet and the Severn-Avon owed their original dividing to a low anticlinal form or ‘swell’ with a Caledonian trend, was worthy of serious consideration, especially as minor anticlines having this trend are already known along this line; and if the suggested synchronism of the two river-systems could eventually be demonstrated, a most important advance would be made in our knowledge of British geology.

The AUTHOR replied to Prof. Groom that the terms ‘Caledonian,’ ‘Armorican,’ etc. were used as indicative of direction only. Movements having those directions had been renewed at many different periods, but he was concerned only with the latest, which had controlled the river-system. He had been unable to find any clear case of a north-north-westerly fault crossing one of the late Caledonian disturbances, except the great trough-faults described in the paper, and these had been dragged out of their course in the disturbed belt. The disturbances in Anglesey, referred to by Mr. Greenly as being crossed by north-north-westerly faults, no doubt belonged to an earlier display of movement in a Caledonian direction. The Pliocene beds mentioned by Mr. Salter did not share in the synclinal folding, and presumably were deposited after it took place. All the faults and fractures referred to in the paper were wholly of pre-Glacial age. He had had in mind a possible connection between the latest movements and the occurrence of earthquakes, and was much interested in the remarks made by Mr. Lake on this subject. The Oolitic escarpment referred to by Dr. Mill, though so conspicuous a feature now, was wholly buried under Upper Cretaceous rocks when the river-system was initiated, and only came into relief as a result of subsequent erosion.